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RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE LA DÉFENSE

Modelling the response of SRMs to impact loading

DGA/CAEPE/EXP

IMEMTS 2009

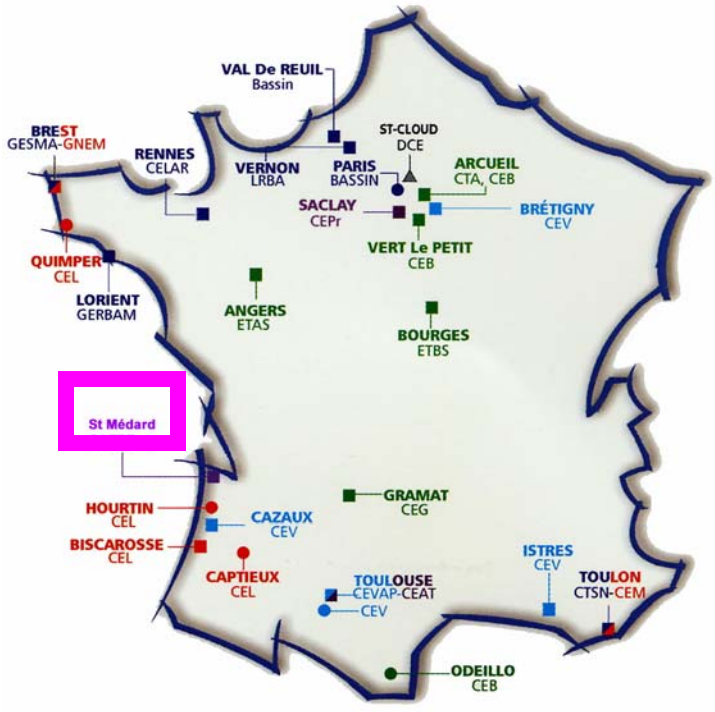
DÉLÉGATION GÉNÉRALE POUR L'ARMEMENT

SUMMARY

1) CAEPE and test facilities
2) Analysis tools – Thermics and mechanics
3) ANSYS/DYNA – SRM under impact loading
4) CRONOS – Hazard areas in case of explosion

1) CAEPE and test facilities

CAEPE AND DGA



- French MoD / DGA / CAEPE
- St Médard en Jalles (33), 330 employees
- Expertise and testing of SRMs
  - Performance
  - Security
  - Aging
- Major programs:
  - Tactical (MdCN, AASM, Mistral …)
  - Strategic (M45/M51, ASMPA)

1) CAEPE and test facilities

PROPULSION TESTS

- 2000 tests carried out in 35 years
- 10 ground testing facilities over 3000 ha
- Motors up to 50 t of propellant and 2500 kN of thrust

1st stage ground testing

MESA facility

1) CAEPE and test facilities

SAFETY TESTS

- Tests according to STANAG standards:
  - SCO, FCO, bullet, light / heavy fragment impact,
  - Drop, shaped charge jet, sympathetic reaction, ...
- 3 safety areas and a drop test tower
- Specimens up to 30 t / 600 kg of propellant / TNT
- Capability of 200 measurements


Drop test tower


Fragment launcher


3 safety areas


Propellant fire

2) Analysis tools

GOALS

CAEPE TESTING ACTIVITIES

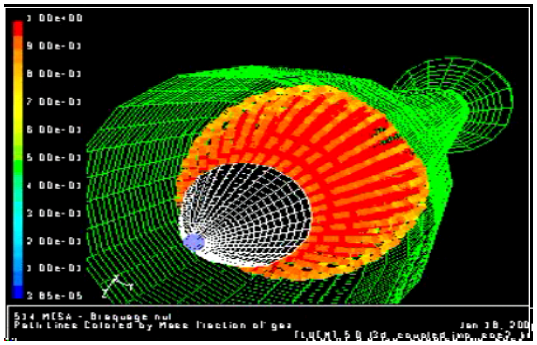
- Preparation of complex tests
- Representativeness of partial tests
- Safety level of operations and tests
- Design of tools and measurements
- Test results analysis

DGA PROGRAM MANAGERS

- Advices on architecture and design
- Analysis of critical issues
- Respect of qualification requirements
- Research programs
- Interactions with the weapon system

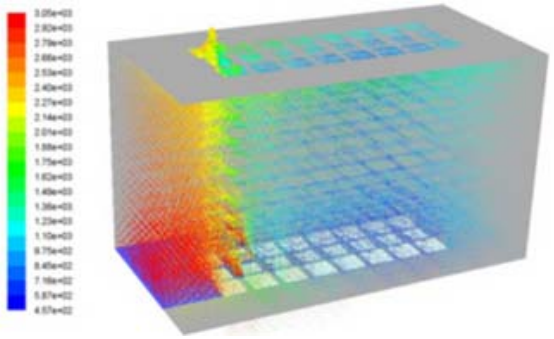
2) Analysis tools

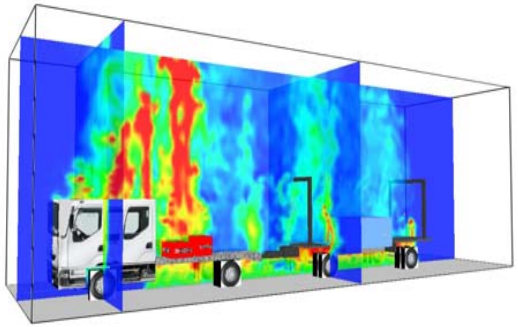
THERMICS



FLUENT / CFX

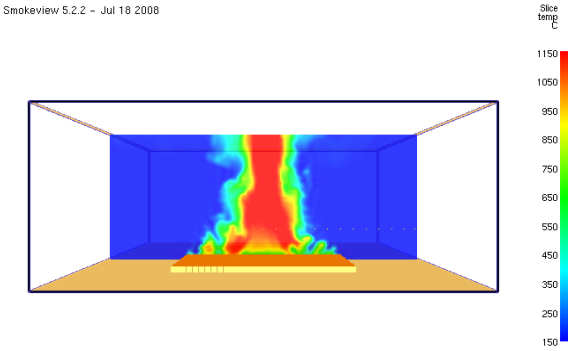
- Fluid dynamics
- Supersonic flaws
- Internal / external
- Motor ignition
- Thermal flux





FDS

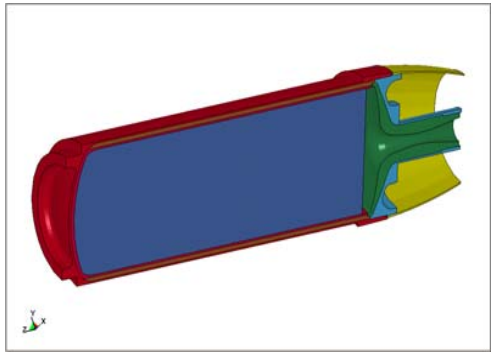
- Fire dynamics
- Subsonic flaws
- Propellant, kerosene
- Safety of operations
- Transport, assembly



2) Analysis tools

MECHANICS

ANSYS

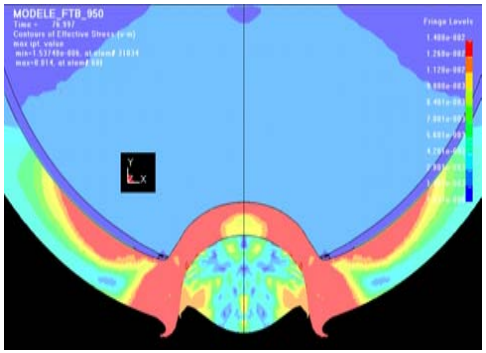


Undamaged

- Storage / flight
- Static / transient
- Multiphysics

➡ Safety margins

DYNA

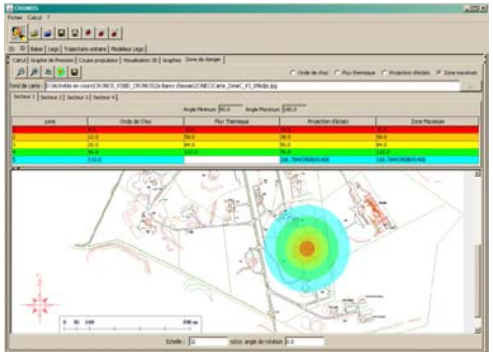


Failure

- Accidental / hostile
- Low / high velocity
- Reactive / unreactive

➡ Reaction level

CRONOS



Post-failure

- SRM explosion
- Fragment projection
- Blast overpressure

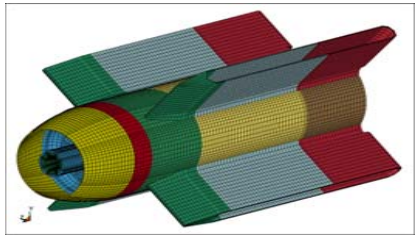
➡ Safety areas

3) ANSYS/DYNA - Response to impact loading

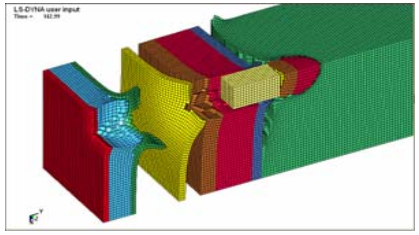
BUILDING THE FE MODEL - 1

Necessary access to detailed and reliable input data

GEOMETRY

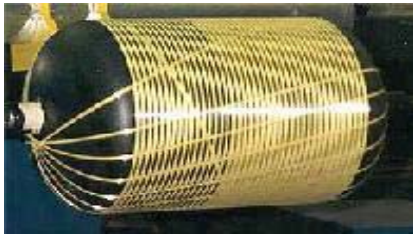


Global model

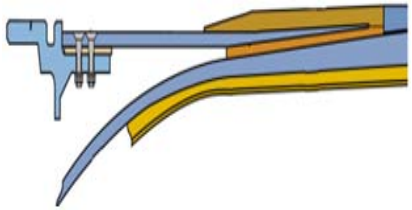


Local model

FABRICATION



Winding law



Assembly

CONSTITUTIVE EQUATIONS

Mechanical response:

- Elasticity	E, ν
with influence of:	
- strain rate	C, p
- plasticity,	σ_y, n
- thermal softening,	m
- hyperelasticity,	C_{ij}, K
- viscosity ...	E_i, τ_i

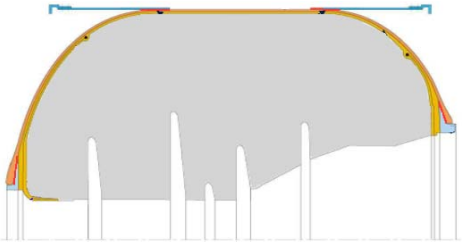
+ Associated failure criterion

+ Equation of State

3) ANSYS/DYNA - Response to impact loading

BUILDING THE FE MODEL - 2

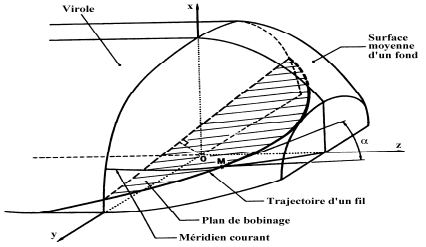
Initial model built using uncertain input data



Geometry

$$C_{ij} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ & C_{22} & C_{23} & 0 & 0 & 0 \\ & & C_{33} & 0 & 0 & 0 \\ & & & C_{44} & 0 & 0 \\ Sym. & & & & C_{55} & 0 \\ & & & & & C_{66} \end{bmatrix}$$

Stiffness matrix



Winding law

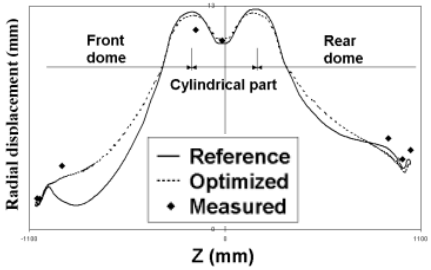
Adjustment by means of inverse identification

Materials properties	Composite structure	E_L = E_L reference +/- 5%
		ET = ET reference +/- 20%
		ET = ET reference -50% and -75% (matrix degradation)
	Skirts	ET = EC = E reference +/- 20%
Winding law	Cylindrical part	α_0 = α_0 reference +/- 1°
	Front dome	Translation of +/- 10°
		Multiplication by +/- 10%
	Rear dome	Translation of +/- 10°
		Multiplication by +/- 10%
Initial geometry	Prior deformation	P_{int} = 10 and 20 bar

Individual parameters influence

Calculation results $\left\{ \begin{matrix} E_L \\ E_T \\ E_J \\ \alpha_0 \\ T_{AV} \\ M_{AV} \\ T_{AR} \\ M_{AR} \\ P_{int} \end{matrix} \right\} = \left\{ \text{Test results} \right\}$

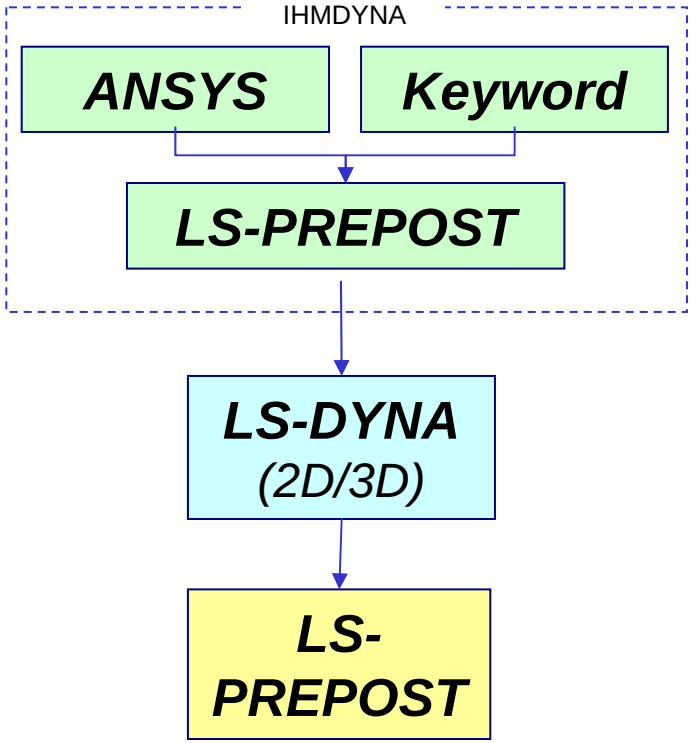
Multivariate analysis



Comparison

3) ANSYS/DYNA - Response to impact loading

BUILDING THE FE MODEL - 3

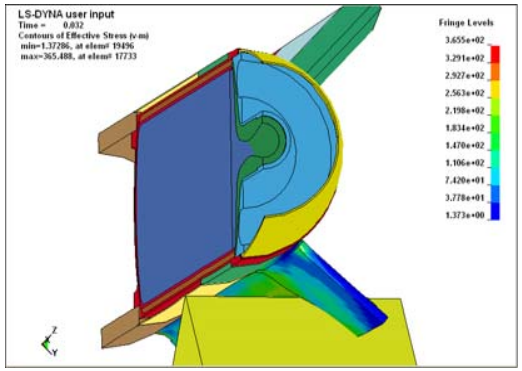


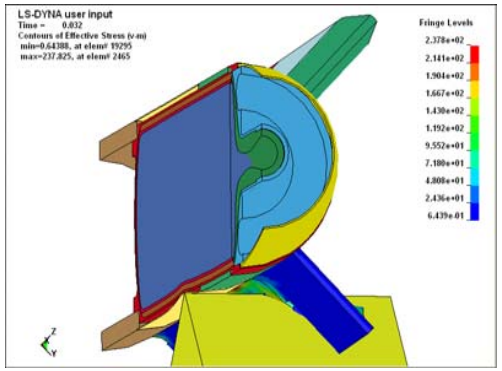
Automated generation of input files

- Meshes for projectiles and targets
- Incidence of projectiles
- Multi-layered targets
- Numerical parameters (contact / solver)

3) ANSYS/DYNA - Response to impact loading

EXAMPLE OF LOW VELOCITY IMPACT





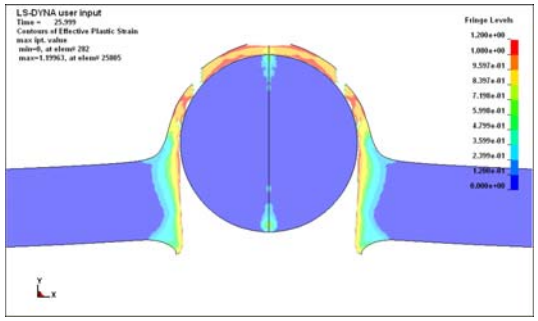
Non-erosive model (FS = infinite)	Real behaviour (FS = numerical)	Erosive model (FS = material)
Optimistic	Needs calibration	Pessimistic

- Strong dependance with numerical parameters
- Erosive criterion not based on material strength
- Model to be calibrated on test results

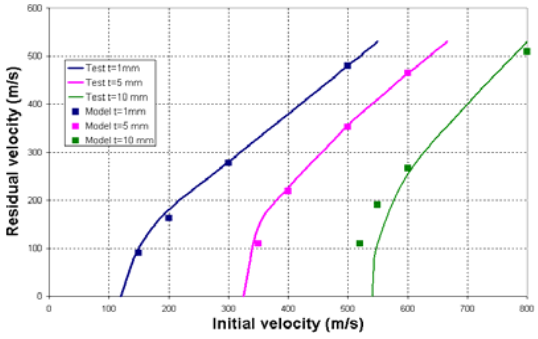
3) ANSYS/DYNA - Response to impact loading

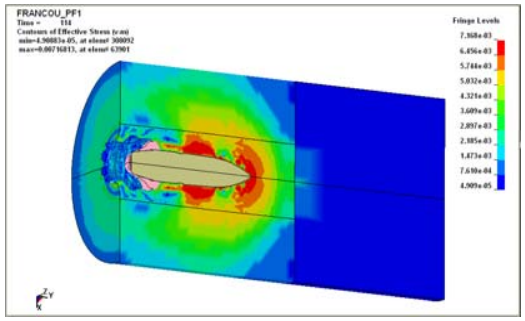
EXAMPLES OF HIGH VELOCITY IMPACT

CALIBRATION



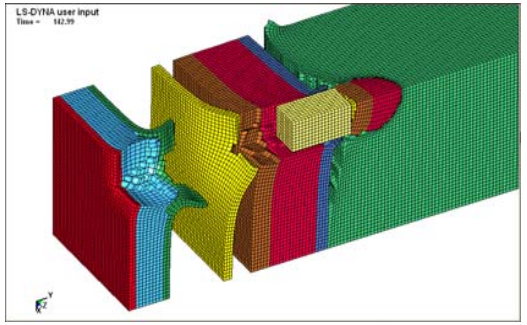
6 g spherical projectile



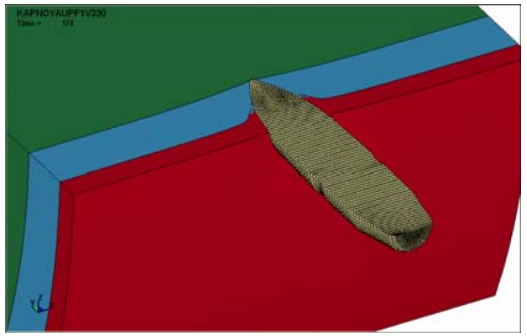


12.7 mm bullet

APPLICATION



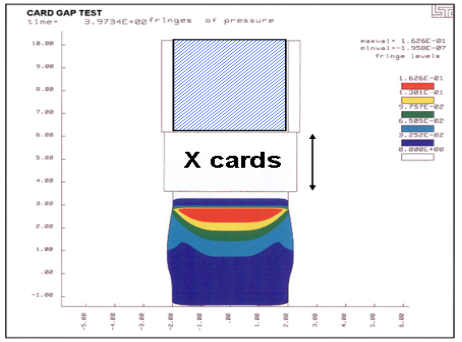
Multi-layered targets

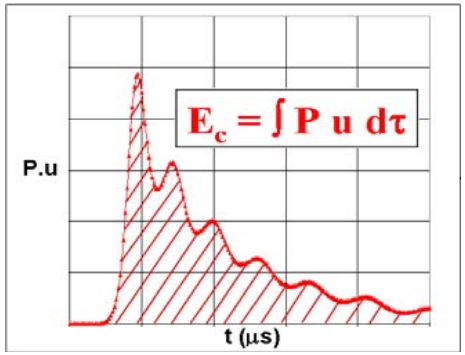


3) ANSYS/DYNA - Response to impact loading

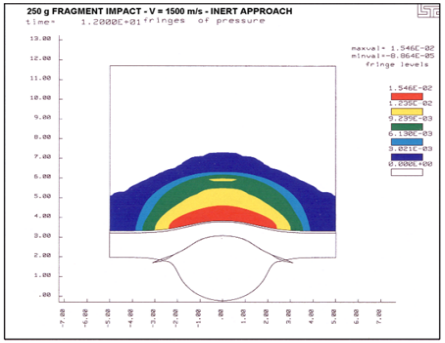
PRELIMINARY APPROACHES TO SDT

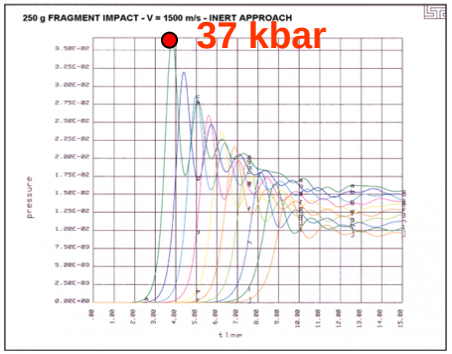
CALIBRATION



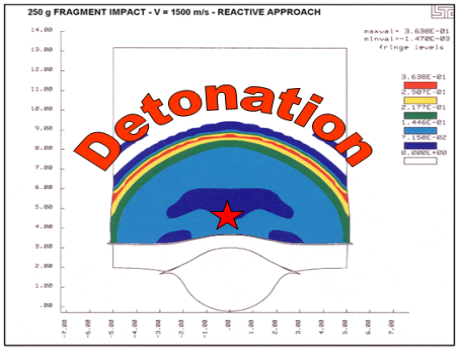


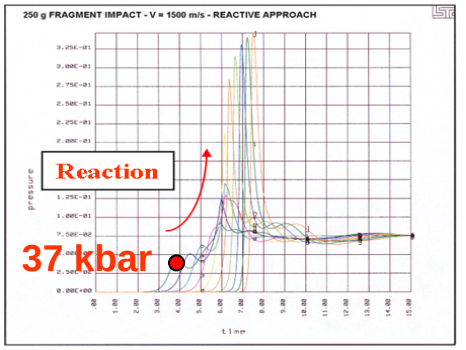
NON-REACTIVE





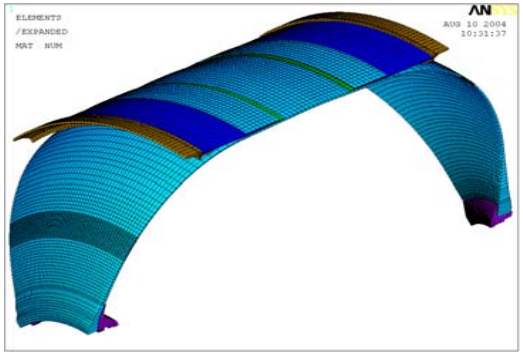
REACTIVE



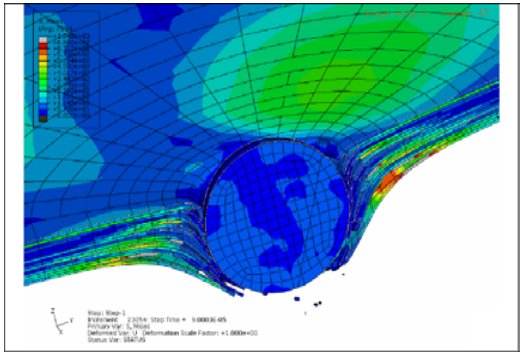


3) ANSYS/DYNA - Response to impact loading

EXTENSION TO COMPOSITE STRUCTURES



FE Model of composite case



Model and test by DGA/CEP

Upcoming tests

4) CRONOS – Hazard areas

HAZARD AREAS PREDICTION TOOL IN CASE OF A SRM PNEUMATIC EXPLOSION
Fragment projection, heat flux and air blast

ipsis
INGÉNIERIE POUR SIGNAUX ET SYSTÈMES

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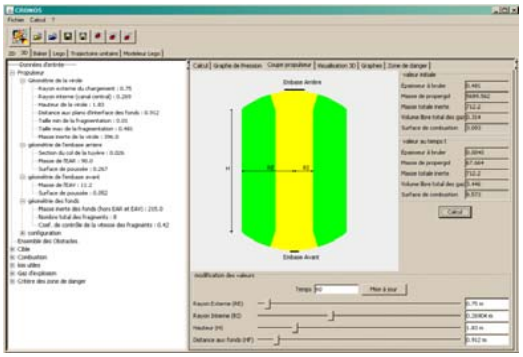
4) CRONOS – Hazard areas

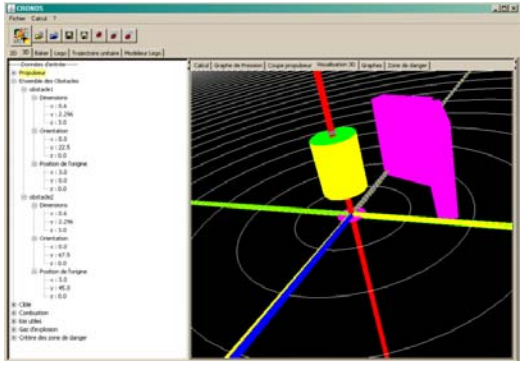
INPUT DATA

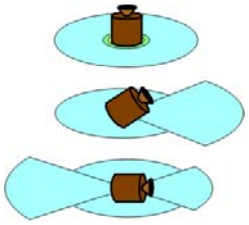
MOTOR



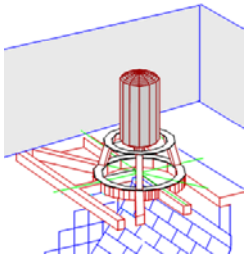
- SRM geometry
- Combustion gases
- Inert masses
- Chamber pressure
- Casing failure pressure

CONFIGURATION



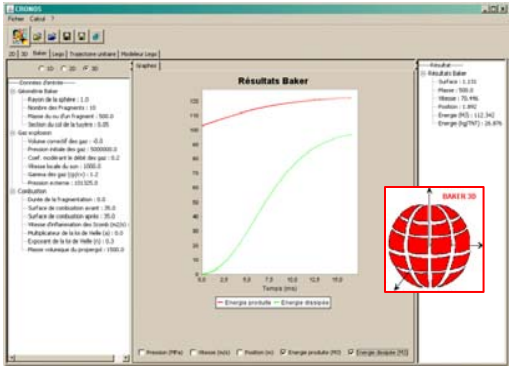


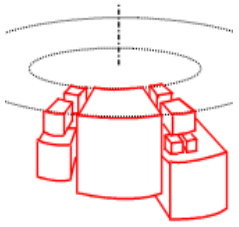
Inclination



Walls

FRAGMENTATION





Pre-defined

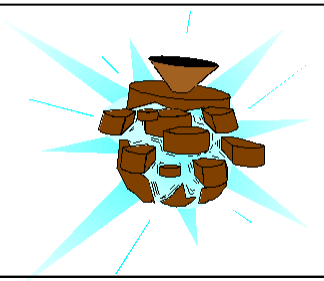
Modeller

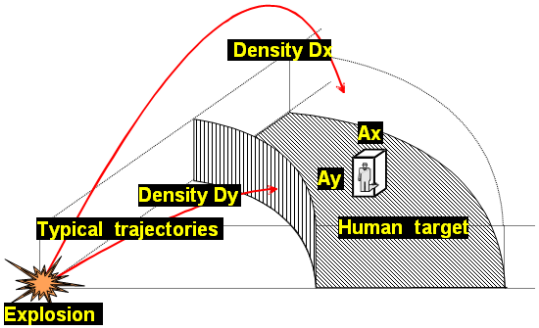
4) CRONOS – Hazard areas

COMPUTATION

Fragment trajectory computed as a result of:

- Internal energy prior to casing burst
- Energy released after burst
- Drag and gravity forces

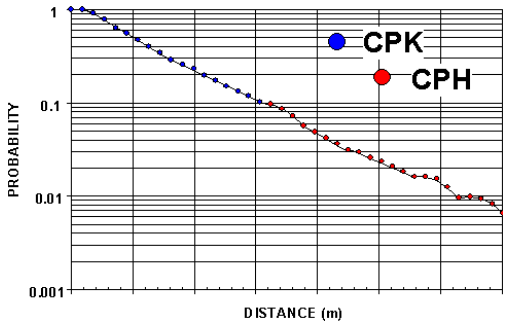




Fragment density and velocity

$$CPH = 1 - e^{-(Ax \times Dx + Ay \times Dy)}$$

$$CPK = 1 - \prod_{ec=min}^{max} (1 - CPH)^{DL(ec)}$$



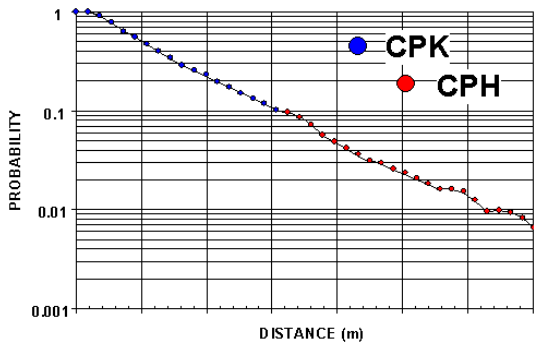
Probability of killing / hitting

Also computed:

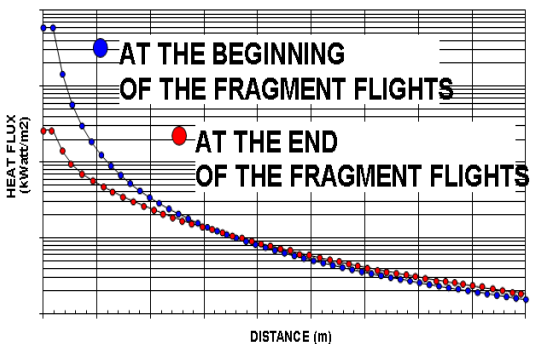
- Heat flux (after explosion and after the flight of all fragments)
- Air blast overpressure (by means of Kinney-Graham's tables)

4) CRONOS – Hazard areas

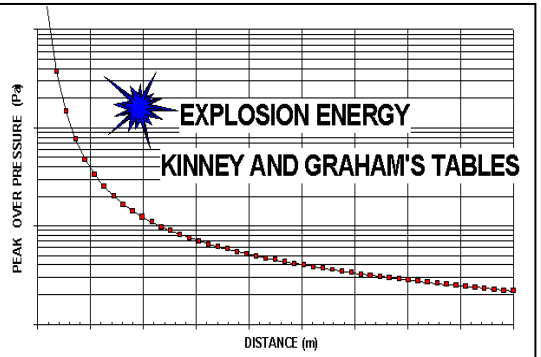
RESULTS



Fragment impact



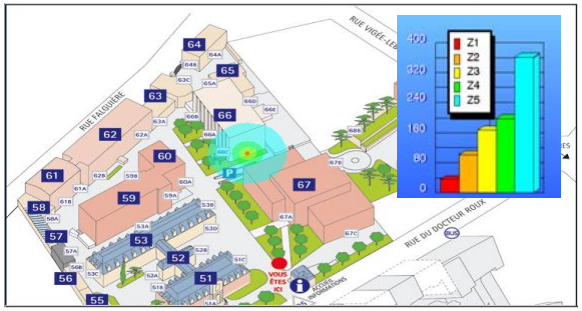
Heat flux



Air blast overpressure

Area	Projection	Heat Flux	Air blast
Z1	CPK > 0.5	(F/S) > 16	Δp > 0.43
Z2	CPK > 0.1	(F/S) > 8	Δp > 0.2
Z3	CPH > 0.03	(F/S) > 5	Δp > 0.14
Z4	CPH > 0.01	(F/S) > 3	Δp > 0.05
Z5	< max range	none (*)	Δp > 0.02

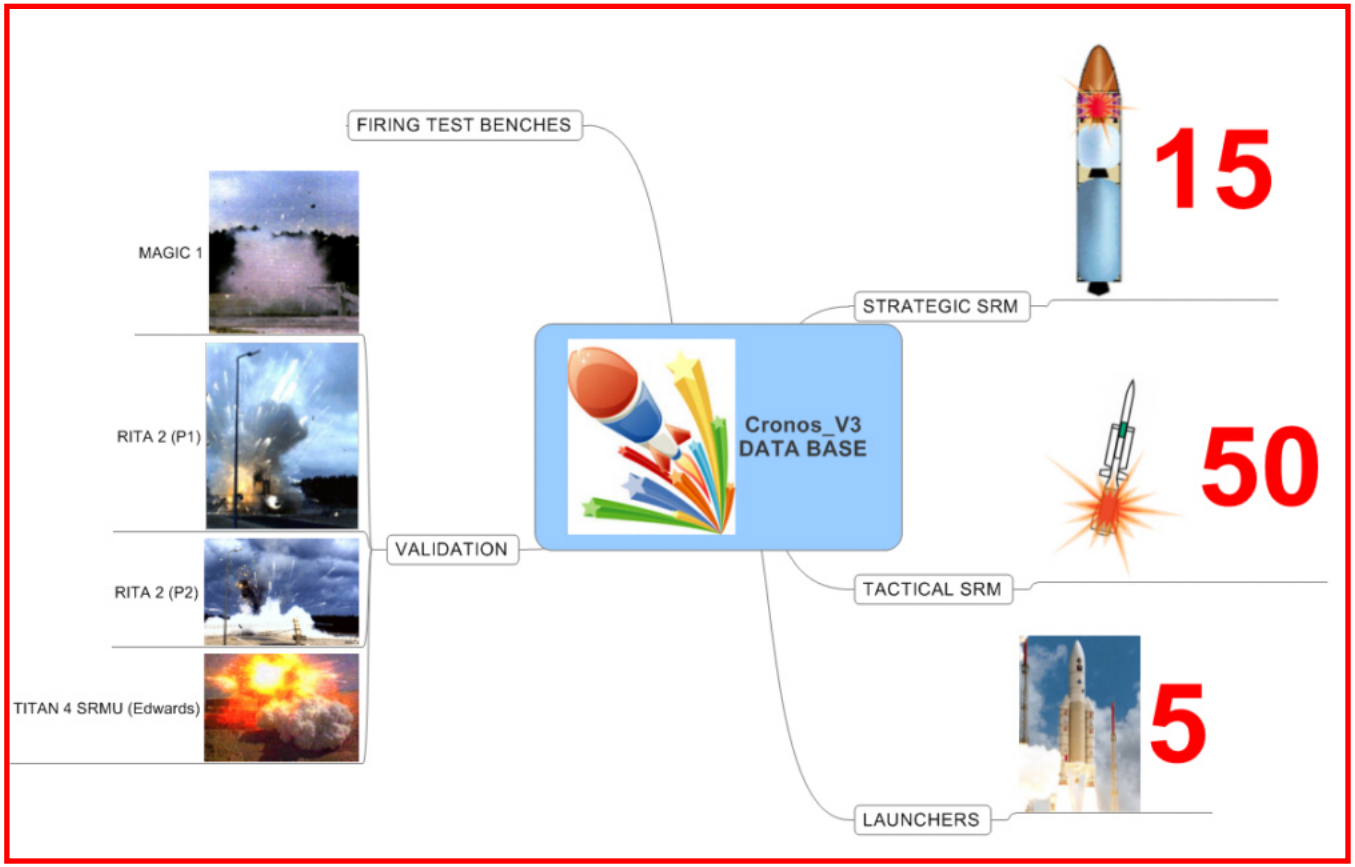
Criteria for safety assessment



Map and safety distances

4) CRONOS – Hazard areas

DATABASE



Any questions ?

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